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TECHNICAL REPORT

Comparison of AFRRI and ETCA dosimetry measurements at AFRRI TRIGA reactor

M. Dooley

G. H. Zeman

DEFENSE NUCLEAR AGENCY

ARMED FORCES RADIOBIOLOGY RESEARCH INSTITUTE

BETHESDA, MARYLAND 20814-5145

REVIEWED AND APPROVED

Gary H. Zeman

GARY H. ZEMAN
Commander, MSC, USN
Chairman
Radiation Sciences Department

Richard I. Walker

RICHARD I. WALKER
Commander, MSC, USN
Acting, Scientific Director

George W. Irving

GEORGE W. IRVING, III
Colonel, USAF, BSC
Director

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A series of irradiations was performed at the AFRRI TRIGA reactor on 10-12 September 1985 as the initial step in establishing a dosimetric link between neutron radiobiology research (using high dose rates close to the source) and military applications experiments (using low dose rates farther from the source). A team of physicists from ETCA, part of the French Ministry of Defense, irradiated several personnel dosimeters both free in air (FIA) and at various depths in an anthropomorphic dosimetry phantom. As reference dosimetry, the ETCA group used fission chambers and AFRRI dosimetrists used paired ionization chambers. The kerma rates measured FIA by the two groups with fundamentally different methods showed excellent agreement (within 5%). However, more work is required to resolve some of the differences observed in the in-phantom measurements. The completion of these experiments marks an important first step in relating mixed-field radiobiology studies to potential combat radiation environments.

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INTRODUCTION

A team of physicists from the Etablissement Technique Central de l'Armament (ETCA), a component of the French Ministry of Defense, performed a series of dosimetric measurements at the Armed Forces Radiobiology Research Institute (AFRRI) TRIGA (Training Research Isotopes General Atomic) reactor on 10-12 September 1985. The purpose of the experiment was to begin the process of comparing results from radiobiology research, done at high dose rates close to the source, to battlefield effects studies, performed at low dose rates far from the source.

The ETCA group used several types of personnel dosimeters (diodes, thermoluminescent dosimeters [TLD's], radiophotoluminescent glass [RPL], fission track detectors, and activation foils) to measure the kerma free in air (FIA) and the dose inside an anthropomorphic dosimetry phantom (a lucite cylinder 30 cm in diameter and 60 cm tall) in exposure room 1 of the AFRRI TRIGA reactor. As reference dosimetry, the ETCA group measured the FIA kerma rate with fission chambers, and AFRRI dosimetrists used ionization chambers to measure the FIA kerma rate and the dose rate midline in the phantom. All measurements were performed in exposure room 1 with the 15-cm shield in place with the center of all arrays set at 70 cm from the tank wall and 120 cm above the floor. Results of ETCA and AFRRI measurements were reported in references 1 and 2, respectively. This report compares the results obtained by the two groups and discusses some of the relevant problems met and the dosimetric information deduced from the experiment.

FIA MEASUREMENTS

The AFRRI group made ionization chamber measurements FIA at the array center point (70 cm from the tank wall and 120 cm above the floor), and the ETCA group made several measurements with fission chambers and passive dosimeters in a styrofoam array that covered the same volume as the AFRRI phantom. The results of these measurements are compared in Tables 1 and 2 and Figures 1 and 2. Table 1A shows that the FIA kerma measured with ionization chambers, fission chambers, and the Np foil all agree exceptionally well (within 5%). However, the diode data are about 10% lower than the AFRRI ionization chamber data. Table 1B shows that the FIA gamma-ray kerma measured by AFRRI ionization chambers and ETCA TLD's and RPL glass do not compare as well as the neutron kerma, with the TLD and RPL results 20%-25% higher than the AFRRI ionization chamber results. However, this large discrepancy in gamma-ray kerma did not affect the comparison of the total kerma, as shown in Table 1C. The total kerma measured by AFRRI and ETCA differs by only about $\pm$ 3%.

The measurements of distance and field size are compared in Table 2. In Table 2A, the AFRRI and ETCA distance measurements show the same trend, but the ETCA-measured neutron kerma falls off more rapidly with distance from the tank wall. Both the AFRRI and ETCA data in Table 2B indicate that laterally the field is fairly symmetrical about the center position.

Table 1. FIA Kerma Measurements in ER1: 15 cm Pb, 70 cm From Tank Wall

A. Neutron kerma

Nominal Reactor Power	AFRRI Ion chambers (cGy/kW · min)	ETCA Fission chambers (cGy/kW · min)		
0.3 kW	6.00	6.00		
1.0 kW	6.00	5.72		
Precision	± 1%	± 3%		
	Ion chambers (Gy)	Fission chambers (Gy)	Np foil (Gy)	Diodes (Gy)
5.0 kW	4.1	3.9	4.1	3.7

B. Gamma kerma (Gy)

	AFRRI	ETCA	
	Ion chambers	TLD's	RPL glass
5.0 kW	0.41	0.51	0.49

C. Total kerma (Gy)

	AFRRI	ETCA			
		Fission chambers		Np foil	
	Ion chambers	TLD's	RPL	TLD's	RPL
5.0 kW	4.51	4.41	4.39	4.61	4.59

Table 2. Spatial Variation Measurements in ER1

A. Normalized neutron kerma versus distance from tank wall

Detector	Distance From Tank Wall (cm): 55	70	85
AFRRI Rh	1.54	1.00	0.65
AFRRI S	1.53	1.00	0.68
ETCA FC[1]	1.62	1.00	0.66
ETCA diodes	1.65	1.00	0.60

B. Normalized neutron kerma versus lateral distance from center at 70 cm from tank wall

Detector	Distance From Center (cm): (Left, facing core) 15	0	(Right) 15
AFRRI Rh	1.02	1.00	1.00
AFRRI S	1.01	1.00	0.98
ETCA FC	--	1.00	0.97
ETCA diodes	0.99	1.00	0.97

[1]Fission chambers

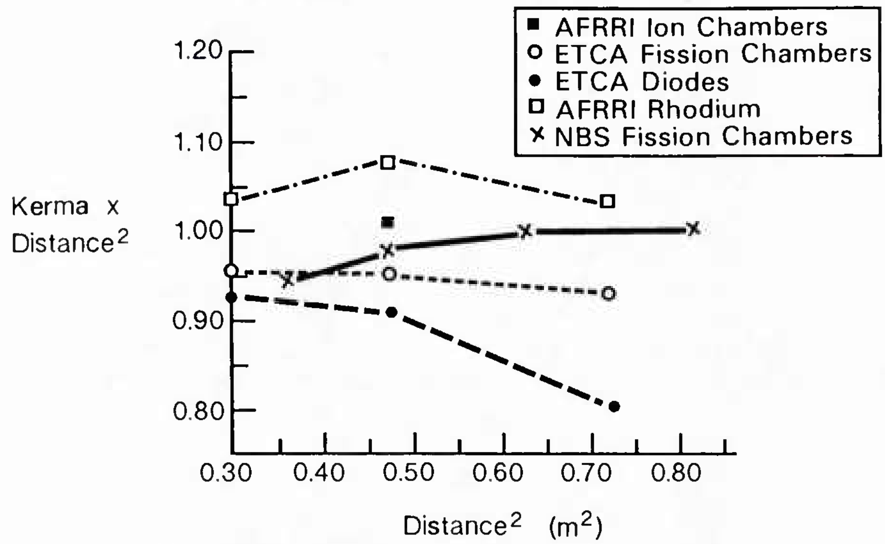

Figure 1. Measurements made in exposure room 1 with 15-cm-Pb shield. Distances were referenced to the reactor tank wall as source center. See text for details.

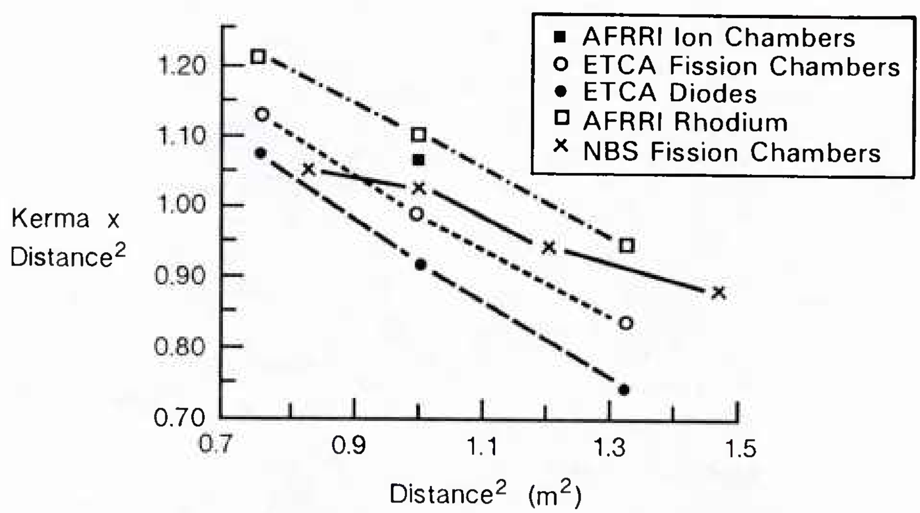

Figure 2. Measurements made in exposure room 1 with 15-cm-Pb shield. Distances were referenced to the center of the reactor core as source center. See text for details.

IN-PHANTOM MEASUREMENTS

Two irradiations were performed with dosimeters inside the anthropomorphic dosimetry phantom. The AFRRI ionization chambers were placed in hollow plastic tubes and inserted in the phantom about 6 cm above the ETCA dosimeters (diodes, TLD's, and RPL glass). Small holes were machined into solid plastic rods so that the ETCA detectors could be placed every 3 cm through the centerline of the phantom. In the first run, the phantom was positioned with the dosimeters parallel to the core centerline so that the depth dose through the phantom was measured. The phantom was rotated 90 degrees for the second run. At that time the dosimeters were perpendicular to the core centerline, and the lateral variation across the midline of the phantom was measured. Note that AFRRI made ionization chamber measurements midline in the phantom only during the second run. The dose for the first run was calculated from the readings of a monitor chamber attached to the lead shield. Table 3 compares the results at the center point in the phantom. The ETCA data are plotted in Figures 3 and 4.

The results of the in-phantom runs show poorer agreement than do the FIA results. ETCA-measured neutron doses at the center of the phantom are 12%-28% higher than those measured with AFRRI ionization chambers. The gamma-ray dose measured by the ETCA TLD's and RPL glass differed from the gamma-ray dose measured by the AFRRI ionization chamber by -25% to +27%. In addition, the TLD and RPL data differed from each other by as much as 40%.

Table 3. Absorbed Dose (Gy) Midline in AFRRI Anthropomorphic Dosimetry Phantom

AFRRI			ETCA				
Ion chambers			n	g		Total	
n	g	Total	Diodes	TLD's	RPL	TLD's	RPL
0.34	1.18	1.52	0.38[1]	0.88	1.50	1.26	1.88
			0.435[2]	1.10	0.99	1.54	1.43

[1]Detectors parallel to core (depth dose)

[2]Detectors perpendicular to core (lateral variation)

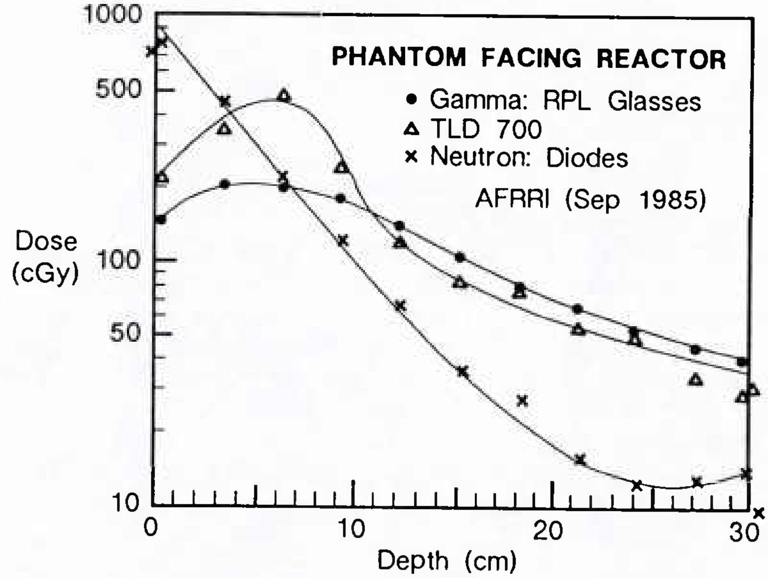

Figure 3. ETCA-measured depth dose through AFRRI anthropomorphic dosimetry phantom (ref. 2)

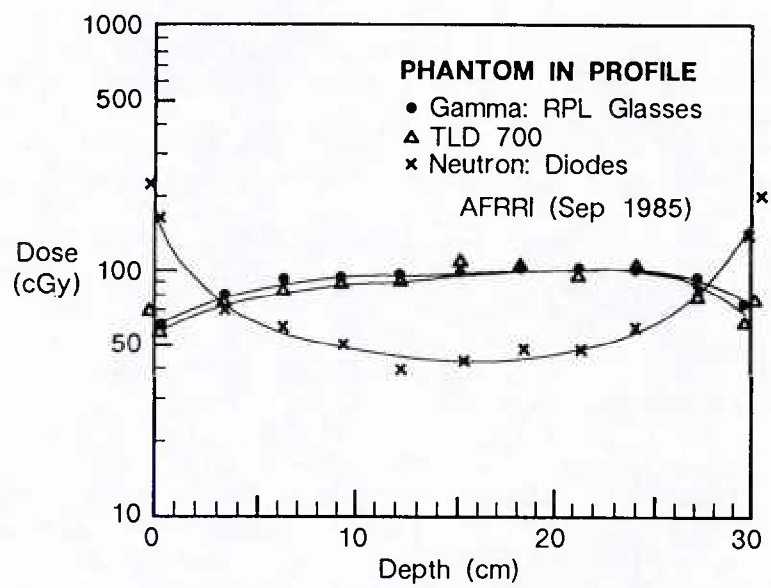

Figure 4. ETCA-measured lateral (side to side) dose through midline of AFRRI anthropomorphic dosimetry phantom (ref. 2)

DISCUSSION

FIA RESULTS

The agreement between AFRRI and ETCA measurements of neutron kerma was excellent at the FIA reference point (70 cm from the tank wall and 120 cm above the floor). This is especially encouraging considering that the methods of dosimetry used by each group were based on fundamentally different physical principles. Note also that the AFRRI ionization chamber results, which indicated a neutron kerma rate of 1.003 mGy/kW•sec, agreed very well with the 1.027 mGy/kW•sec measured at low nominal power levels in the ion chamber intercomparison between the National Bureau of Standards (NBS) and AFRRI for this same configuration (3). The FIA gamma-ray measurements did not compare as well, with as much as a 25% difference between the ETCA and AFRRI data. This difference may be due in part to the sensitivity of the TLD 700's and RPL glass to thermal and fast neutrons.

IN-PHANTOM RESULTS

As indicated above, the in-phantom measurements of the ETCA and AFRRI groups did not show good agreement. Several concerns about the experiment that may have contributed are discussed below.

(a) The positioning of the phantom and the dosimeters inside the phantom is extremely critical. The ETCA dosimeters were placed 15.2 cm inside the phantom, and the AFRRI chambers were centered 15 cm inside the phantom. Although this is a very small difference, Figure 3 shows that the dose is changing very rapidly in this region, on the order of 15% per cm. A small positioning error could translate into a much larger discrepancy in the measured neutron dose.

(b) Differences were also seen in the radiation geometry between the AFRRI ionization chambers and the ETCA detectors. The ionization chambers were placed in hollow plastic tubes and inserted into the phantom, whereas the ETCA insert rod was made of solid plastic with small holes for the dosimeters. It is possible that these subtle geometry differences altered the neutron scattering and absorption in the vicinity of the detectors.

(c) The neutron dose measured by the diodes was not consistent for the two phantom runs. The diode response may be dependent on orientation, or this discrepancy could have been due to the positioning problem mentioned above. Unfortunately, ionization chamber data were available for only the second run, so the positioning theory cannot be corroborated. More work needs to be done to resolve this disparity.

(d) The two types of ETCA gamma-ray dosimeters did not agree well with the AFRRI ionization chambers in the phantom, nor did they agree with each other. These dosimeters may have a fast neutron sensitivity dependent on neutron energy as well as a sensitivity to thermal neutrons. In addition, ETCA has attributed the disagreement in part to calibration procedures (2), and further studies by ETCA are under way to clarify this discrepancy.

FIA SPATIAL VARIATION

Figures 1 and 2 depict how well the neutron kerma follows an inverse square relationship with distance from the tank wall (Figure 1) and the core center (Figure 2). Plotted on the ordinate is the neutron kerma multiplied by the distance squared ($mGy \cdot m^2/kW{\cdot}sec$), and on the abscissa is the distance squared (m^2). The data are normalized to the AFRRI ion chamber measurements at 0.7 m from the tank wall (1.0 m from the core center). A horizontal line in these curves means that the neutron kerma decreases with distance proportionally to the inverse of the distance squared, as expected from a point source. The data from Figures 1 and 2 indicate that the effective source center is close to the reactor tank wall, not at the core center. This same trend was demonstrated by fission chamber measurements obtained by NBS at AFRRI in March 1985 (4), and these data are included in Figures 1 and 2.

DEPTH DOSE MEASUREMENTS

The results of the ETCA in phantom measurements are summarized in Figures 3-5. In Figure 3, the uncorrected depth dose data are plotted. In Figure 5, the inverse square portion of the data is removed so that only attenuation in the phantom is considered. Also provided in Figure 5 are similar data taken by ETCA at the SILENE reactor (5). The neutron depth dose data show exponential attenuation until about 26 cm into the phantom, with an approximate half-value layer of about 4.5 cm (using the corrected data). These data agree with previous large-phantom studies at AFRRI (6-8). The exponential attenuation indicates that the shape of the neutron energy spectrum does not change much through a hydrogenous phantom. However, at the exit side of the phantom, the neutron dose seems to increase slightly. This was also seen in previous work and has been attributed to the incidence of scattered neutrons on the backside of the phantom (5,7).

As noted earlier, a large discrepancy was seen between data for the TLD and the RPL glass gamma-ray depth dose, especially in the first few centimeters in the phantom (see Figure 3). The ETCA group attributed this to the thermal neutron sensitivity of the TLD's, and it considers the RPL glass to be more accurate (2). The RPL glass data indicate that the gamma-ray dose increases until about 5 cm into the phantom and then decreases approximately exponentially through the rest of the phantom. This is probably because in the first few centimeters of the plastic, the production of gamma rays ($H[n, \gamma]^2H$) dominates over attenuation, but as the neutron flux decreases, the production rate also decreases and attenuation becomes more significant.

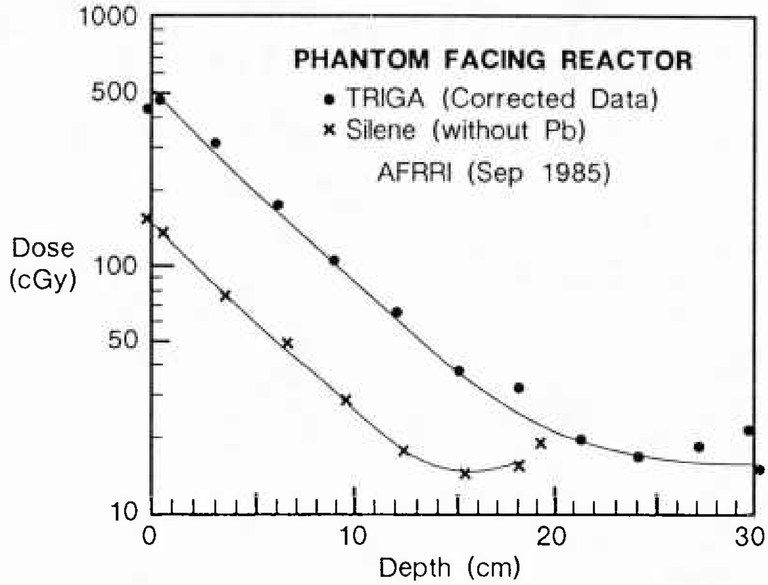

Figure 5. ETCA-measured neutron depth dose, corrected for inverse square (ref. 2)

In Figure 4, the lateral variation of the neutron and gamma-ray doses across the midline of the phantom is plotted. The data indicate that the dose is not symmetric about the center of the phantom. Because the FIA data indicated at most a 3% difference between the right and left sides, the asymmetry is probably a manifestation of the positioning difficulties mentioned above. In any event, the neutron dose decreases by a factor of about 5 from the outside edge of the phantom to the center, while the gamma-ray dose increases by about 50%.

SUMMARY

Using fundamentally different dosimetry techniques, ETCA and AFRRI obtained close agreement of the measured FIA kerma in exposure room 1 of the AFRRI TRIGA reactor. Many valuable data were collected concerning depth dose in an anthropomorphic phantom and also the spatial variation in the exposure room. However, more work is required to resolve some of the discrepancies found in the in-phantom measurements. This experiment was an important first step in relating mixed-field radiobiology studies to research concerning military applications on the nuclear battlefield.

REFERENCES

1. AFRRI Form 60, Dosimetry Report RUR#85-129, dated 19 September 1985. Armed Forces Radiobiology Research Institute, Bethesda, MD.

2. Serbat, A., Dhermain, J., and Le Teurnier, D. Rapport Preliminaire Concernant L'Experimentation a L'Army Force Radiobiology Research Institute en Septembre 1985. Establissement Technique Central de l'Armament, Centre D'Etudes Du Bochet, October 1985.

3. NBS Annual Progress Report on Program Support of Neutron Dosimetry, Work Unit Code 00078. DNA IACRO 83-847, October 1, 1984.

4. Dooley, M., Goodman, L. J., Zeman, G. H., Schwartz, R. B., Eisenhauer, C. M., and Blake, P. K. Ionization chamber intercomparison in mixed neutron and gamma-ray radiation fields by National Bureau of Standards and Armed Forces Radiobiology Research Institute. Technical Report TR86-3. Armed Forces Radiobiology Research Institute, Bethesda, MD, 1986.

5. Barry, F., and Lemaire, G. Silene. A typical solution-fueled irradiation facility. Proceedings of 1985 Workshop of Research Study Group on Assessment of Ionizing Radiation Injury in Nuclear Warfare. Published for NATO RSG.5 by Defense Research Establishment, Ottawa, Canada, September 1985, pp. 1-13.

6. Monroy, R. L., Zeman, G. H., Patchen, M. L., Darden, J. D., Feser, C. L., and MacVittie, T. J. Re-evaluation of the neutron effectiveness in the canine model. Proceedings of 1985 Workshop of Research Study Group on Assessment of Ionizing Radiation Injury in Nuclear Warfare. Published for NATO RSG.5 by Defense Research Establishment, Ottawa, Canada, September 1985, pp. 151-184.

7. Verrelli, D. M. Dosimetry for neutron radiation studies in miniature pigs. AFRRI Technical Note TN71-2. Armed Forces Radiobiology Research Institute, Bethesda, MD, 1971.

8. Verrelli, D. M., and Shosa, D. W. Comparison of dose patterns in a miniature pig exposed to neutron and to gamma radiation. AFRRI Technical Note TN71-5. Armed Forces Radiobiology Research Institute, Bethesda, MD, 1971.